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Commissioner for Patents

A translation of European Patent No. 0 871 230 A1 is enclosed.

TOM DOUGHERTY
PRIMARY EXAMINER
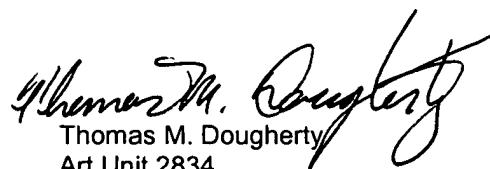
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Art Unit 2834

METHOD AND DEVICE FOR CHARGING AND DISCHARGING A PIEZOELECTRIC ELEMENT

Jörg Reineke & Alexander Hock

EUROPEAN PATENT OFFICE

EUROPEAN PATENT NO. 0 871 230 A1

METHOD AND DEVICE FOR CHARGING AND DISCHARGING A PIEZOELECTRIC ELEMENT

[Verfahren und Vorrichtung zum Laden und Entladen eines piezoelektrischen Elements]

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The present invention pertains to a method according to the preamble of Claim 1 and a /2* device according to the preamble of Claim 10, i.e., a method and a device for charging and discharging a piezoelectric element, wherein both the charging and the discharging take place at least in part via an element acting essentially as an inductor for the charging and discharging current.

The piezoelectric elements currently being considered in detail are particularly, but not exclusively, piezoelectric elements used as actors or actuating elements. Piezoelectric elements

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* [Numbers in the right margin indicate pagination in the original foreign text.]

can be used for such purposes because, as is known, they have the property of being able to contract or expand as a function of a voltage applied to them.

The practical implementation of actuators with piezoelectric elements proves to be advantageous particularly when the actuator in question must carry out rapid and/or frequent motions.

The use of piezoelectric elements as actuators proves to be advantageous for fuel injector nozzles for internal combustion engines, among other things. With regard to the usability of piezoelectric elements in fuel injector nozzles, reference is made, for instance, to EP 0 371 469 B1 and EP 0 379 182 B1.

Piezoelectric elements are capacitive loads which, as indicated to some extent already, contract and expand corresponding to the respective charge state or, in other terms, the resulting or applied voltage.

For charging and discharging a piezoelectric element, two basic principles are known, namely, charging and discharging via an ohmic resistor and charging and discharging via a coil, both the ohmic resistor and the coil serving, among other purposes, to limit the charge current appearing while charging and the discharge current appearing while discharging.

The first variant, i.e., charging and discharging via an ohmic resistor, is illustrated in Figure 9.

The piezoelectric element, labeled in Figure 9 with reference number 101, is connected to a charging transistor 102 and a discharging transistor 103.

Charging transistor 102 is driven by a charging amplifier 104 and, in the conductive state, connects piezoelectric element 101 to a positive supply voltage; discharging transistor 103 is driven by a discharging amplifier 105 and, in the conductive state, connects piezoelectric element 101 to ground.

In the conductive state of charging transistor 102, a charging current flows through it, by which piezoelectric element 101 is charged. With an increasing charge of piezoelectric element 101, the potential present there increases and its external dimensions change accordingly. Blocking of charging transistor 102, i.e., an interruption or termination of the charging process, has the effect that the charge stored in piezoelectric element 101, or the potential resulting there, and thus the current external dimensions of piezoelectric element 101, are retained essentially unchanged.

In the conductive state of discharging transistor 103, a discharging current flows through it, by which piezoelectric element 101 is discharged. With an increasing discharge of piezoelectric element 101, the potential present there decreases and its external dimensions change accordingly. Blocking of charging transistor 103, i.e., an interruption or termination of the discharging process, has the effect that the charge still stored in piezoelectric element 101, or

the potential resulting there, and thus the current external dimensions of piezoelectric element 101, are retained essentially unchanged.

Charging transistor 102 and discharging transistor 103 act like controllable ohmic resistors for the charging and discharging currents, respectively. The controllability of the charging or discharging current which this creates makes it possible to have the charging and discharging process run exactly as desired. The charging current flowing through charging transistor 102 and the discharging current flowing through discharging transistor 103, however, cause not inconsiderable power losses there. The energy loss consumed in the transistors is at least twice as high per charge-discharge cycle as the energy stored in piezoelectric element 101. This high loss energy causes a strong heating of charging transistor 102 and discharging transistor 103, which is obviously a disadvantage.

Not least of all because of this, the already mentioned second variant for charging and discharging the piezoelectric element, i.e., charging and discharging via a coil, is used; a practical implementation of this second variant is illustrated in Figure 10.

The piezoelectric element to be charged or discharged, labeled in Figure 10 with reference number 201, is a component of a charging circuit that can be closed via a charging switch 202 and of a discharging circuit that can be closed via a discharging switch 206, the charging circuit consisting of a series connection of charging switch 202, a diode 203, a charging /3 coil 204, piezoelectric element 201 and a voltage source 205, and the discharging circuit consisting of a series connection of discharging switch 206, a diode 207, a discharging coil 208 and piezoelectric element 201.

Diode 203 of the charging circuit prevents a current discharging the piezoelectric element from flowing in the charging circuit. Diode 203 and charging switch 202 can be implemented together as a semiconductor switch.

Diode 207 of the discharging circuit prevents a current charging the piezoelectric element from flowing in the discharging circuit. Like diode 203 and charging switch 202, diode 207 and charging [sic; discharging] switch 206 can be implemented together as a semiconductor switch.

If normally open charging switch 202 is closed, then a charging current flows in the charging circuit, by which piezoelectric element 201 is charged; the charge stored in piezoelectric element 201 or the potential resulting therefrom, and thus also the current external dimensions of piezoelectric element 201, are retained essentially unchanged after it is charged.

If normally open discharging switch 206 is closed, then a discharging current flows in the discharging circuit, by which piezoelectric element 201 is discharged; the charge state of piezoelectric element 201 or the potential resulting therefrom, and thus also the current external dimensions of piezoelectric element 201, are retained essentially unchanged after it is discharged.

Charging coil 204 or discharging coil 206 represents an element acting essentially as an inductor for the charging current or the discharging current, respectively; charging coil 204 and piezoelectric element 201, as well as discharging coil 206 and piezoelectric element 201, form a series LC oscillator during, respectively, the charging and discharging of the piezoelectric element.

Circuits of the type described with reference to Figure 10 and methods for charging and discharging piezoelectric elements using such circuits are known from the publications EP 0 371 469 B1 and EP 0 379 182 B1 already mentioned initially.

The methods and devices known from the cited publications and described according to their fundamental principles above are methods according to the preamble of Claim 1 or devices according to the preamble of Claim 10.

Since both the charging circuit and the discharging circuit in circuits according to Figure 10 are free of significant ohmic resistances, the heat energy generated by the charging and discharging of the piezoelectric element (due to the flow of charging current and discharging current through ohmic resistances) is extraordinarily small.

On the other hand, a relatively large space is needed for the practical implementation of such circuits, particularly because of the not inconsiderable size of charging coil 204 and discharging coil 208, whereby the charging and discharging of piezoelectric elements via an element acting essentially as an inductor for the charging or discharging current is in certain cases not possible or in any case not without additional space.

.The present invention is therefore based on the problem of refining the method according to the preamble of Claim 1 and the device according to the preamble of Claim 10 such that an efficient charging and discharging of piezoelectric elements is possible even under cramped conditions.

This problem is solved according to the invention by the characteristics claimed in the characterizing part of Claim 1 (method) or the characteristics claimed in the characterizing part of Claim 10 (device).

According to these, it is provided that the charging and discharging current is conducted at least in part via the same element functioning as an inductor (characterizing part of Claim 1) or that at least one element functioning as an inductor is arranged such that both the charging current and the discharging current can be conducted through it (characterizing part of Claim 10).

The at least partial charging or discharging of the piezoelectric element via an element acting essentially as an inductor for the charging or discharging current, for instance, via a coil or an element acting like a coil, makes it possible to keep the charging current path or the discharging current path essentially free of electrical loads; thereby, on the one hand, very little

energy is consumed (because the energy loss is low and the energy withdrawn from the piezoelectric element can be returned to the voltage source or stored back into a capacitor) and thereby, on the other hand, the heating of the circuit appearing during charging and discharging can be kept very low. As a result, the individual components (including the energy supply) can be designed for relatively low power levels, and the measures previously sometimes required for cooling can either be eliminated completely or kept very small in scale.

Conducting the charging current and the discharging current via the same element functioning as inductor, i.e., conducting the charging current and the discharging current via, for /4 instance, the same coil or the same element functioning as an inductor, also makes it possible to keep to a minimum the number of components, more precisely, the number of elements functioning as inductors, which has a very clear effect on the size of the device under consideration, because of the not inconsiderable size of these elements.

Thus it is possible in a simple and elegant manner to perform the charging of piezoelectric elements, even under cramped conditions.

The device according to the invention can also be manufactured more simply and cheaply than is the case for conventional devices.

Advantageous refinements of the invention are the subject matter of the subordinate claims.

The invention is described in greater detail below on the basis of embodiments with reference to the drawings. Shown are:

Figure 1, a circuit according to the invention suitable for charging and discharging a piezoelectric element according to the method of the invention;

Figure 2, a representation to explain the conditions existing during a first charging phase (charging switch 3 closed) in the circuit according to Figure 1;

Figure 3, a representation to explain the conditions existing during a second charging phase (charging switch 3 again opened) in the circuit according to Figure 1;

Figure 4, a representation to explain the conditions existing during a first discharging phase (discharging switch 5 closed) in the circuit according to Figure 1;

Figure 5, a representation to explain the conditions existing during a second discharging phase (discharging switch 5 again opened) in the circuit according to Figure 1;

Figure 6, the time course of the voltage and current curves existing during the operation of the circuit according to Figure 1;

Figure 7 a circuit according to the invention suitable for the sequential charging and discharging of several piezoelectric elements according to the method of the invention;

Figure 8, the time course of the voltage and current curves existing during the operation of the circuit according to Figure 7;

Figure 9, a conventional circuit for charging and discharging a piezoelectric element via elements functioning as ohmic resistors for the charging and discharging current;

Figure 10, a conventional circuit for charging and discharging a piezoelectric element via elements functioning as coils for the charging and discharging current.

The piezoelectric elements of which the charging and discharging will be described in greater detail below can be used, for instance, as actuators in fuel injector nozzles (particularly in so-called common rail injectors) for internal combustion engines. There is no restriction to such a use of the piezoelectric elements, however; the piezoelectric elements can be used in principle in any device for any purpose.

It is assumed that the piezoelectric elements expand in response to charging and contract in response to discharging. It goes without saying that the invention can be applied even if the exact opposite is the case.

A circuit for performing the method according to the invention for charging and discharging a piezoelectric element will now be described with reference to Figure 1.

The piezoelectric element to be charged in the example under consideration is labeled in Figure 1 with the reference number 1.

As is evident from Figure 1, one of the terminals of piezoelectric element 1 is permanently grounded (connected to a first pole of a voltage source), while the other of the terminals of the piezoelectric element is connected to the second pole of the voltage source via a coil 2 and a parallel circuit of a charging switch 3 and a diode 4, and to the first pole of the voltage source via coil 2 and a parallel circuit of a discharging switch 5 and a diode 6

The voltage source consists of a battery 7 (for instance, an automobile battery) a downstream DC-DC converter 8 and a capacitor 9 serving as a buffer capacitor downstream of the latter. By means of this arrangement, the battery voltage (for instance, 12 V) is converted to another, essentially arbitrary, DC voltage and provided as a supply voltage.

The charging and discharging of piezoelectric element 1 in the example under /5 consideration is done cyclically. That is to say, charging switch 3 and discharging switch 5 are repeatedly closed and opened during the charging and discharging process.

The conditions resulting from this are explained below with reference to Figures 2-5, of which Figures 2 and 3 illustrate the charging of piezoelectric element 1 and Figures 4 and 5 illustrate the discharging of piezoelectric element 1.

Charging switch 3 and discharging switch 5 are open whenever and so long as no charging or discharging of piezoelectric element 1 is taking place. The circuit in the stationary state shown in Figure 1 is in this state. That is to say, piezoelectric element 1 retains its charge essentially unchanged and no currents flow.

Upon the start of charging piezoelectric element 1, charging switch 3 is repeatedly opened and closed; discharging switch 5 remains open.

When charging switch 3 is closed, the conditions shown in Figure 2 result. That is to say, a closed circuit consisting of a series connection of piezoelectric element 1, capacitor 9 and coil 2 is formed, in which a current $i_{LE}(t)$ flows, as indicated by arrows in Figure 2. This flow of current has the effect that energy is stored in coil 2. The flow of energy into coil 2 is caused by the positive potential difference between capacitor 9 and piezoelectric element 1.

When charging switch 3 is opened shortly (e.g., a few μs) after its closure, the conditions shown in Figure 3 result. That is to say, a closed circuit consisting of a series connection of piezoelectric element 1, diode 6 and coil 2 is formed, in which a current $i_{LA}(t)$ flows, as indicated by arrows in Figure 3. This flow of current has the effect that the energy stored in coil 2 flows completely into piezoelectric element 1. Corresponding to the supply of energy to the piezoelectric element, the potential resulting there and its external dimensions increase. After the transport of energy from coil 2 to piezoelectric element 1 has been accomplished, the already-mentioned stationary state of the circuit according to Figure 1 is again achieved.

Then, or even somewhat earlier or also only later (depending on the desired time course of the charging process), charging switch 3 is again closed and opened, with the processes just described recurring. Due to the additional opening and closing of charging switch 3, the energy stored in piezoelectric element 1 increases (the energy already stored in the piezoelectric element and the new energy supplied are cumulative) and the potential resulting at the piezoelectric element and its external dimensions increase accordingly.

If one repeats the above-described closing and opening of charging switch 3 a plurality of times, then the resulting potential at the piezoelectric element and the expansion of the piezoelectric element increase incrementally (on this, see the representation in Figure 6, to be explained later).

If charging switch 3 has been closed and opened a predetermined number of times and/or if piezoelectric element 1 has reached the desired charge state, then the charging of the piezoelectric element is terminated by leaving charging switch 3 open.

If piezoelectric element 1 is to be discharged, this is accomplished by a repeated closing and opening of discharging switch 5; charging switch 3 remains open.

When discharging switch 5 is closed, the conditions shown in Figure 4 result. That is to say, a closed circuit consisting of a series connection of piezoelectric element 1 and coil 2 is formed, in which a current $i_{EE}(t)$ flows, as indicated by arrows in the figure. This flow of current has the effect that the energy stored in piezoelectric element 1 (or part of it) is transported into coil 2. Corresponding to the transfer of energy from piezoelectric element 1 to coil 2, the resulting potential at the piezoelectric element and its external dimensions decrease.

When discharging switch 5 is opened shortly (e.g., a few μs) after its closure, the conditions shown in Figure 5 result. That is to say, a closed circuit consisting of a series connection of piezoelectric element 1, capacitor 9, diode 4 and coil 2 is formed, in which a current $i_{EA}(t)$ flows, as indicated by arrows in the figure. This flow of current has the effect that the energy stored in coil 2 flows completely into capacitor 9. After the transport of energy from coil 2 to capacitor 9 has been accomplished, the already-mentioned stationary state of the circuit according to Figure 1 is again achieved.

Then, or even somewhat earlier or also only later (depending on the desired time course of the charging process), discharging switch 5 is again closed and opened, with the processes just described recurring. Due to the additional opening and closing of discharging switch 5, the energy stored in piezoelectric element 1 decreases further and the potential resulting at the piezoelectric element and its external dimensions decrease accordingly.

If one repeats the above-described closing and opening of discharging switch 5 a plurality /6 of times, then the resulting potential at the piezoelectric element and the extent of the piezoelectric element decrease incrementally (on this, see the representation in Figure 6).

If discharging switch 3 [sic; 5] has been closed and opened a predetermined number of times and/or if piezoelectric element has reached the desired charge state, then the discharging of the piezoelectric element is terminated by leaving discharging switch 5 open.

If one operates the circuit shown in Figure 1, more precisely, if one carries out the charging and discharging of piezoelectric element 1, as described above, then the current and voltage curves shown in Figure 6 result.

The curves shown in Figure 6 are provided with symbols representing their measured parameters. Of these symbols

□   represents the potential U_B resulting at capacitor 9,

◊   the voltage resulting at piezoelectric element 1, and

∨   the current flowing through coil 2.

The current and voltage curves shown in Figure 6 illustrate the charging process (in the range from 100 μs to 300 μs on the time scale) and the discharging process (in the range from 400 μs to 600 μs on the time scale); they are immediately understandable with the knowledge of the construction, function and operation of the circuit according to Figure 1 as imparted above and require no further explanation.

As is evident from Figure 6, the voltage resulting at piezoelectric element 1 has a homogeneous and recognizably well-controllable curve.

At the same time, the circuit through which the charging and discharging of the piezoelectric element is accomplished, more precisely, the circuit according to Figure 1, is

constructed as simply as possible and is optimal in efficiency. Three factors contribute to this, namely

1) that the charging and discharging is done via the same coil (namely coil 2);

2) that the energy loss due to heat generation in ohmic resistances is negligibly small; and

3) that the energy stored in the piezoelectric element is stored back in capacitor 9

essentially in its entirety and is thus available for immediate reuse.

The first point makes it possible to keep the number of components, particularly the inherently relatively large coils, to a minimum. The second and third point make it possible to design battery 7 and DC-DC converter 8 for relatively low power levels.

All of the cited points, whether alone or in combination, enable or at least contribute to housing the circuits to be provided for the charging and discharging of piezoelectric elements in the smallest space and to keeping the costs for manufacturing and operating them to a minimum.

By means of the method for charging and discharging piezoelectric elements described in its essence above, or by means of the circuit suited to carrying out this method, it is possible for a plurality of piezoelectric elements, instead of only one piezoelectric element, to be successively charged and discharged.

A circuit which makes this possible is presented in Figure 7.

The circuit shown in Figure 7 is based on the circuit shown in Figure 1; corresponding elements are provided with the same reference numbers. The "only" difference is that piezoelectric element 1 of Figure 1 is replaced by a parallel circuit consisting of an additional diode 10 and a plurality (n) of additional piezo branches 11, 12, ..., 1n, each piezo branch consisting of a series circuit of a piezoelectric element 11_1, 12_1, ..., $1n_1$ and a parallel circuit consisting of a selection switch 11_2, 12_2, ..., $1n_2$ and a diode 11_3, 12_3, ..., $1n_3$.

Diode 10 prevents the appearance of negative voltages at the piezoelectric elements, since the latter could be destroyed thereby under certain circumstances.

The parallel selection switch/diode pairs in the individual piezo branches, i.e., selection switch 11_2 and diode 11_3 in piezo branch 11, selection switch 12_2 and diode 12_3 in piezo branch 12 and selection switch $1n_2$ and diode $1n_3$ in piezo branch 1n, can be implemented by electronic switches with parasitic diodes such as MOSFETs.

The charging and discharging of piezoelectric elements 11_1, 12_1, ..., $1n_1$ is accomplished in essentially the same way as the charging and discharging of piezoelectric element 1 of Figure 1. That is to say, charging switch 3 is repeatedly closed and opened for charging and discharging switch 5 is repeatedly closed and opened for discharging.

Which piezoelectric element or elements 11_1, 12_1, ..., $1n_1$ is charged during the repeated closing and opening of charging switch 3 is determined by selection switch 11_2, 12_2, ..., $1n_2$. In each case, all those piezoelectric elements 11_1, 12_1, ..., $1n_1$ whose selection switch 11_2, 12_2, ...,

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$1n_2$ is closed during the repeated closing and opening of charging switch 3 are charged.

The selection of the piezoelectric elements 11_1, 12_1, ..., $1n_1$ to be charged by closing the associated selection switch 11_2, 12_2, ..., $1n_2$ and the cancellation of the selection by opening the switches in question generally takes place outside the charging process. In certain cases, however, such as when several piezoelectric elements 11_1, 12_1, ..., $1n_1$ are to be charged simultaneously to differing extents, the opening and closing of selection switches 11_2, 12_2, ..., $1n_2$ can take place during the charging process.

The processes occurring during the charging of the selected piezoelectric elements 11_1, 12_1, ..., $1n_1$ are essentially identical to the processes occurring in the circuit of Figure 1. Figures 2 and 3 and the explanations referring thereto are also valid; the only difference is that it is not piezoelectric element 1 which is charged, but one or more of piezoelectric elements 11_1, 12_1, ..., $1n_1$.

The discharging of piezoelectric elements 11_1, 12_1, ..., $1n_1$ takes place independently of the position of the associated selection switch 11_2, 12_2, ..., $1n_2$ because the discharge current bringing about the discharging of the respective piezoelectric elements can flow via the associated diodes 11_3, 12_3, ..., $1n_3$. Therefore, all partially or completely charged piezoelectric elements 11_1, 12_1, ..., $1n_1$ are discharged by the discharging process.

The processes occurring during the discharging of piezoelectric elements 11_1, 12_1, ..., $1n_1$ are essentially identical to the processes occurring in the circuit of Figure 1. Figures 4 and 5 and the explanations referring thereto are also valid; the only difference is that it is not piezoelectric element 1 which is discharged, but piezoelectric elements 11_1, 12_1, ..., $1n_1$.

If one operates the circuit shown in Figure 7 such that piezoelectric elements 11_1, 12_1, ..., $1n_1$ are successively charged and discharged, as described above, then the current and voltage curves shown in Figure 8 result.

The curves shown in Figure 8 are provided with symbols representing their measured parameters. Of these symbols

□   represents the potential U_B resulting at capacitor 9,

◊   the current flowing through coil 2,

∇   the voltage resulting at piezoelectric element 11_1,

Δ   the voltage resulting at piezoelectric element 12_1, and

°   the voltage resulting at piezoelectric element $1n_1$.

The current and voltage curves shown in Figure 8 illustrate the charging and discharging process of piezoelectric element 11_1 (in the range from roughly 0.1 ms to 0.7 ms on the time scale), of piezoelectric element 12_1 (in the range from roughly 0.8 ms to 1.4 ms on the time scale) and the charging and discharging process of piezoelectric element $1n_1$ (in the range from roughly 1.5 ms to 2.1 ms on the time scale); they are immediately understandable with the

knowledge of the construction, function and operation of the circuit according to Figure 7 as imparted above and require no further explanation.

As is evident from Figure 8, the voltage resulting at the piezoelectric elements has a nearly linear and recognizably well-controllable curve.

At the same time, the circuit through which the charging and discharging of the piezoelectric elements is accomplished, more precisely, the circuit according to Figure 7, is constructed as simply as possible and is optimal in efficiency. Contributing to this, as already for the circuit of Figure 1, is again that the charging and discharging is done via the same coil (namely coil 2), that the loss energy due to heat generation in ohmic resistances is negligibly small; and that the energy stored in the piezoelectric element [sic; elements] is stored back in capacitor 9 essentially in its entirety and is thus available for immediate reuse.

The first point again makes it possible to keep the number of components, particularly the inherently relatively large coils, to a minimum. The second and third points make it possible to design battery 7 and DC-DC converter 8 for relatively low power levels.

All of the cited points, whether alone or in combination, enable or at least contribute to housing the above-considered circuit (circuit of Figure 7) for the charging and discharging of piezoelectric elements in the smallest space and to keeping the costs for manufacturing and operating it to a minimum.

In the described embodiments, a coil was used in each case as the element functioning as an inductor. There is no restriction to this, however. In place of the coil, other elements functioning as inductors such as DC/DC transformers, transformers and so on can be used (with the appropriately modified circuit structure and circuit operation).

There is also no restriction to performing the charging and discharging cyclically, as described. Alternatively or supplementarily, the charging and discharging can be carried out in some other manner. Among other possibilities, it could be provided to perform the charging and/or discharging in whole or in part via one or more charging and discharging circuits functioning as oscillators. /8

In summary, it can be stated that the device and the method according to the invention make it possible in a simple and elegant manner to perform the charging and discharging of piezoelectric elements efficiently, even under cramped conditions.

Claims

1. Method for charging and discharging a piezoelectric element (1; 11_1, 12_1, ..., $1n_1$), wherein both the charging and the discharging is done at least in part via an element (2) functioning as an inductor for the charging and discharging current, characterized in that the

charging current and discharging current are conducted at least in part through the same element functioning as an inductor.

2. Method according to Claim 1, characterized in that a coil is used as the element (2) functioning as an inductor.

3. Method according to Claim 2, characterized in that coil (2) and piezoelectric element $(1; 11_1, 12_1, ..., 1n_1)$ are connected in series.

4. Method according to one of the preceding claims, characterized in that the charging of piezoelectric element $(1; 11_1, 12_1, ..., 1n_1)$ is done by repeated closing and opening of a charging switch (3), wherein the closing of the charging switch brings about a storage of energy in the element (2) functioning as an inductor and wherein the opening of the charging switch brings about the emission of the energy stored in the element functioning as an inductor to the piezoelectric element.

5. Method according to one of the preceding claims, characterized in that the discharging of piezoelectric element $(1; 11_1, 12_1, ..., 1n_1)$ is done by repeated closing and opening of a discharging switch (5), wherein the closing of the discharging switch brings about a transfer of the energy stored in the piezoelectric element to the element (2) functioning as an inductor and wherein the opening of the discharging switch brings about the emission of the energy stored in the element functioning as an inductor.

6. Method according to Claim 5, characterized in that the energy stored in the element (2) functioning as an inductor is emitted to a buffer capacitor (9) downstream of a supply voltage source (7, 8).

7. Method according to one of the preceding claims, characterized in that element (2) functioning as an inductor is used for charging and discharging a plurality of piezoelectric elements $(11_1, 12_1, ..., 1n_1)$ provided in branches connected in parallel.

8. Method according to Claim 7, characterized in that the piezoelectric element or elements $(11_1, 12_1, ..., 1n_1)$ that are to be charged during the respective charging process are selected via associated selection switches $(11_2, 12_2, ..., 1n_2)$.

9. Method according to one of the preceding claims, characterized in that the piezoelectric element or elements $(1; 11_1, 12_1, ..., 1n_1)$ are protected from being charged to a negative potential.

10. Device for charging and discharging a piezoelectric element $(1; 11_1, 12_1, ..., 1n_1)$, wherein both the charging and the discharging is done at least in part via an element (2) functioning as an inductor for the charging and discharging current, characterized in that at least one element functioning as an inductor is arranged such that both the charging current and the discharging current can be conducted through it.
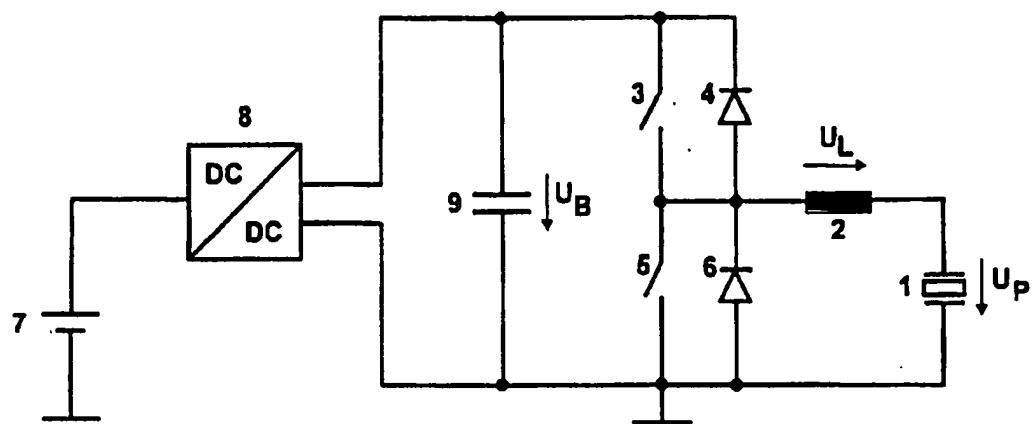
FIG. 1
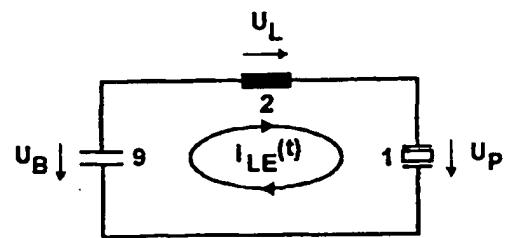
FIG. 2
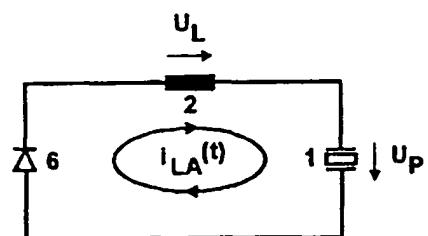
FIG. 3
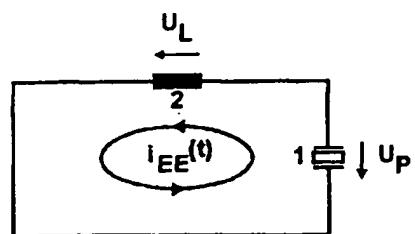
FIG. 4
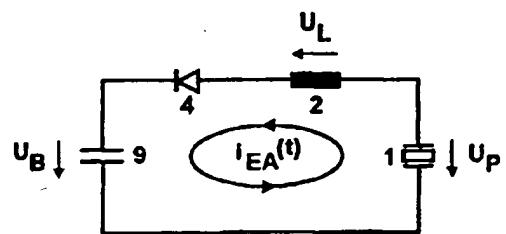
FIG. 5
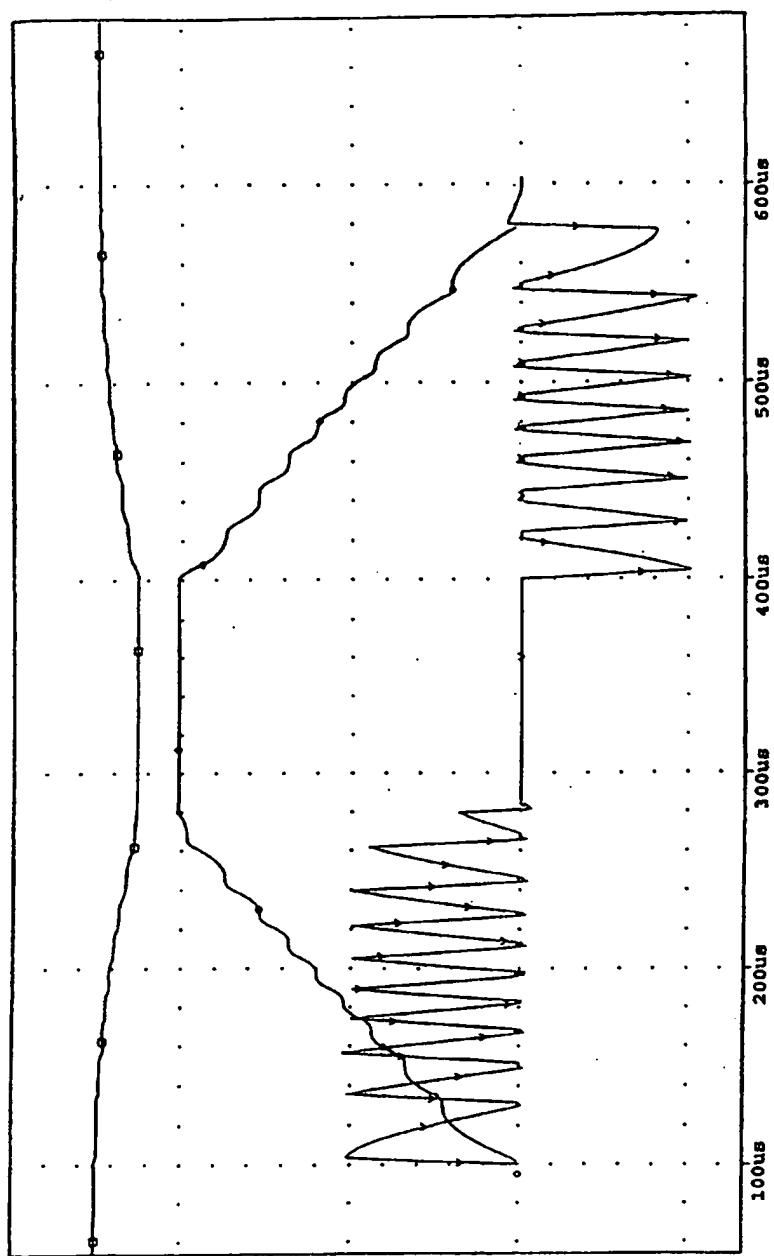
FIG. 6
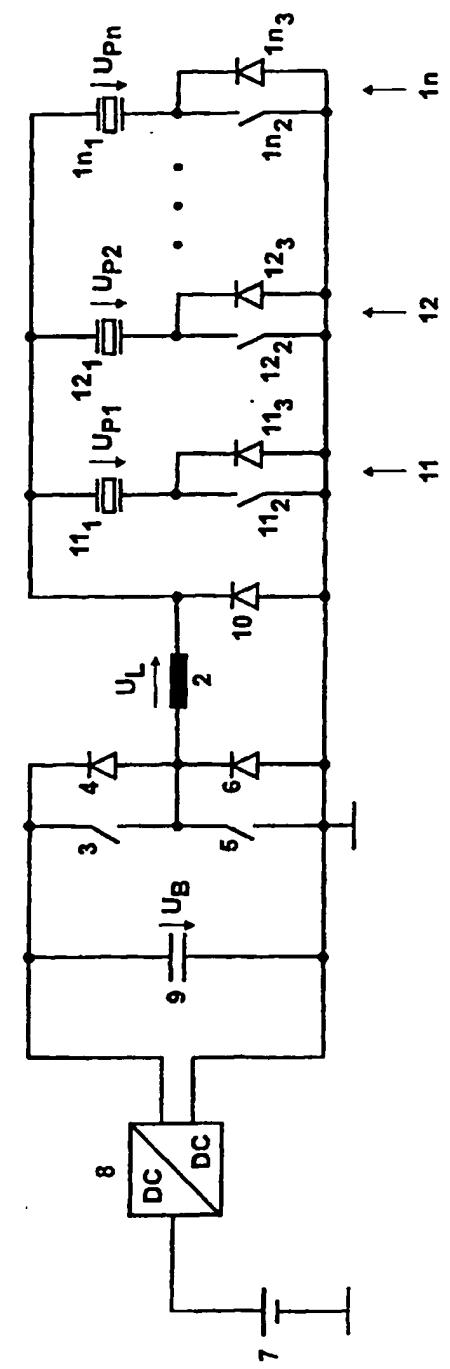
FIG. 7
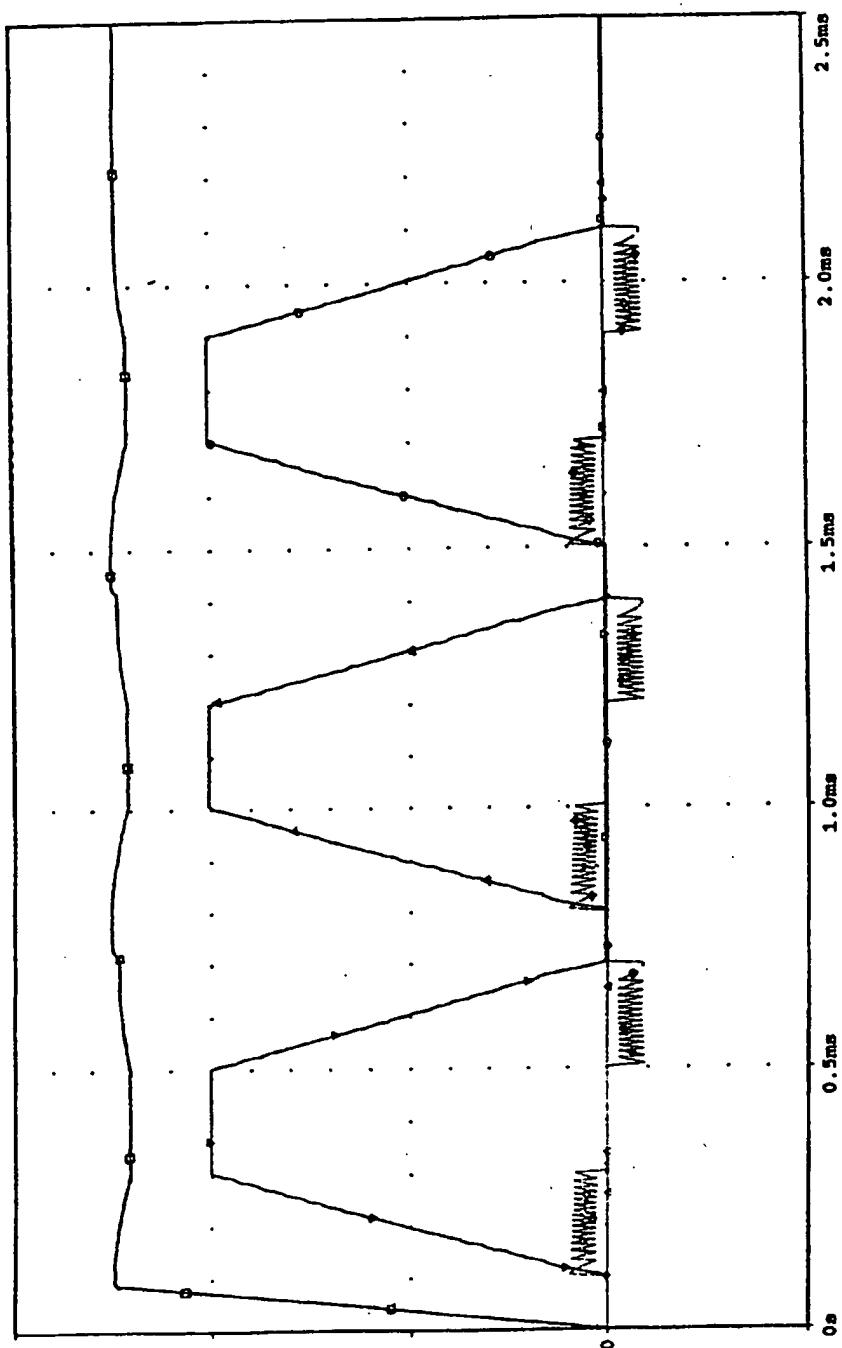
FIG. 8
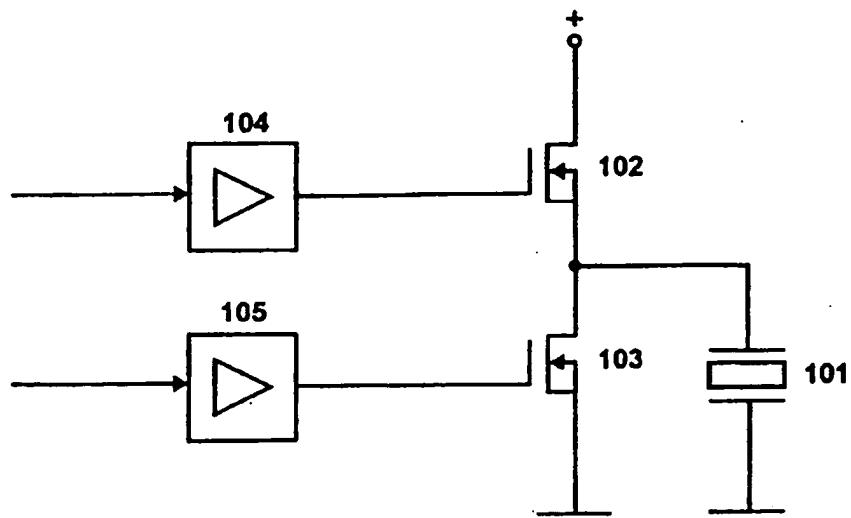
FIG. 9
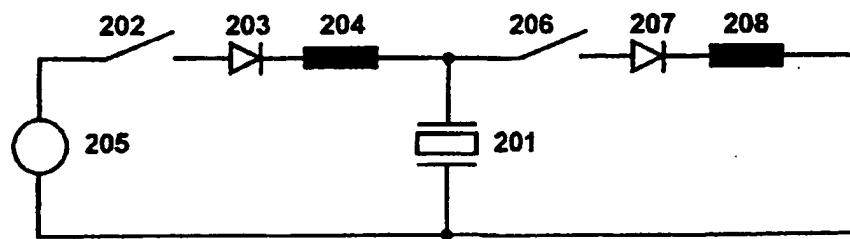
FIG. 10

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EUROPEAN SEARCH REPORT

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.⁶)
X	PATENT ABSTRACTS OF JAPAN vol. 016, no. 282 (M-1269), June 23, 1992 & JP 04 071859 A (BROTHER IND LTD), March 6, 1992, *Abstract* ---	1, 4	H01L41/04
X	DE 44 35 832 A (UNIV DRESDEN TECH) April 11, 1996 *Abstract; Figure 1* ---	1	
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			TECHNICAL FIELDS SEARCHED (Int. Cl.⁶)
			H01L

The present search report has been drawn up for all claims.

Place of search	Date of completion of the search	Examiner
The Hague	July 17, 1998	L. Pelsers

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